DEPARTEMEN TEKNIK MESIN

Teknologi Minyak Bumi dan Gas Alam

Fluid Transport Equipment

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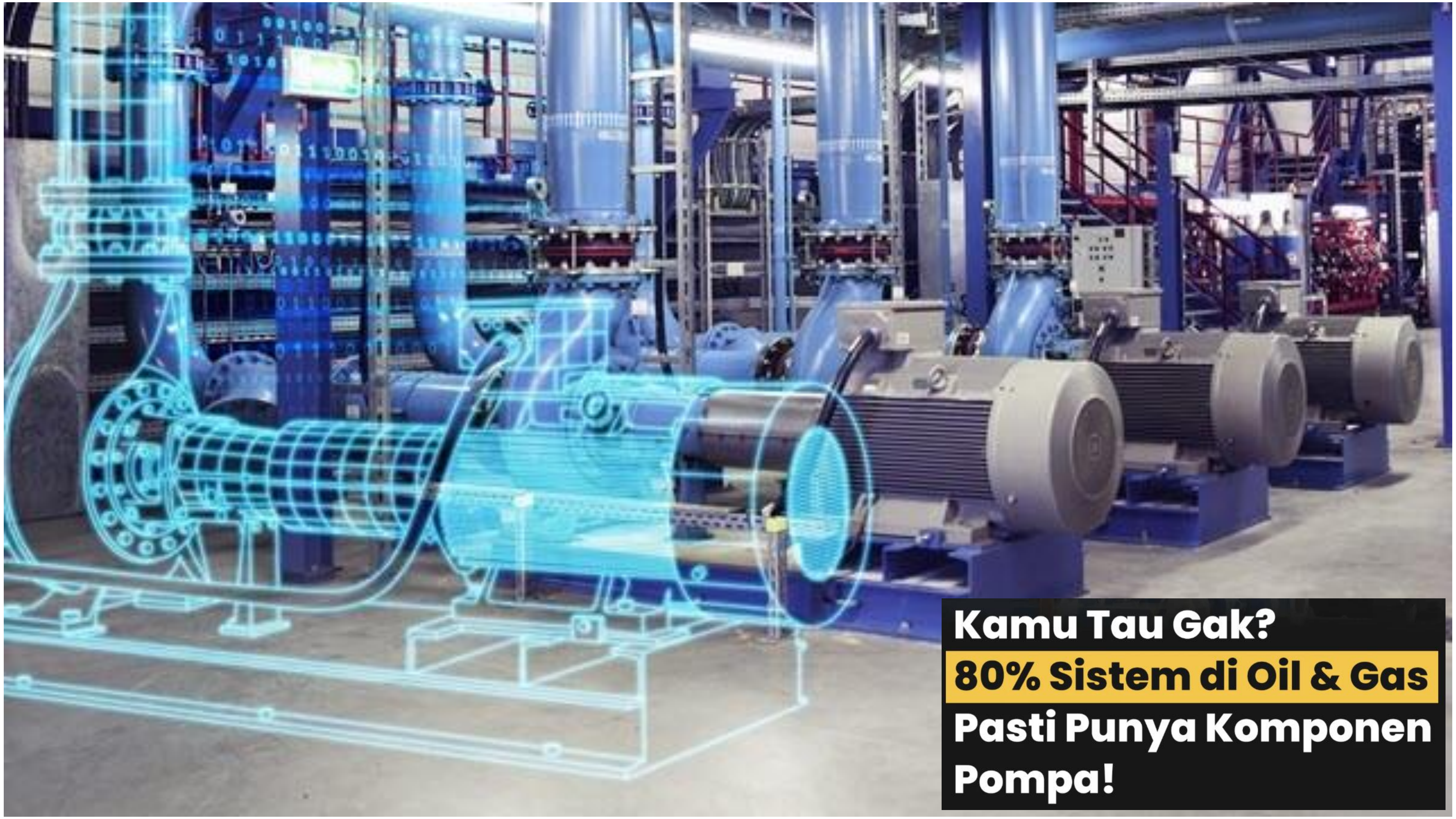
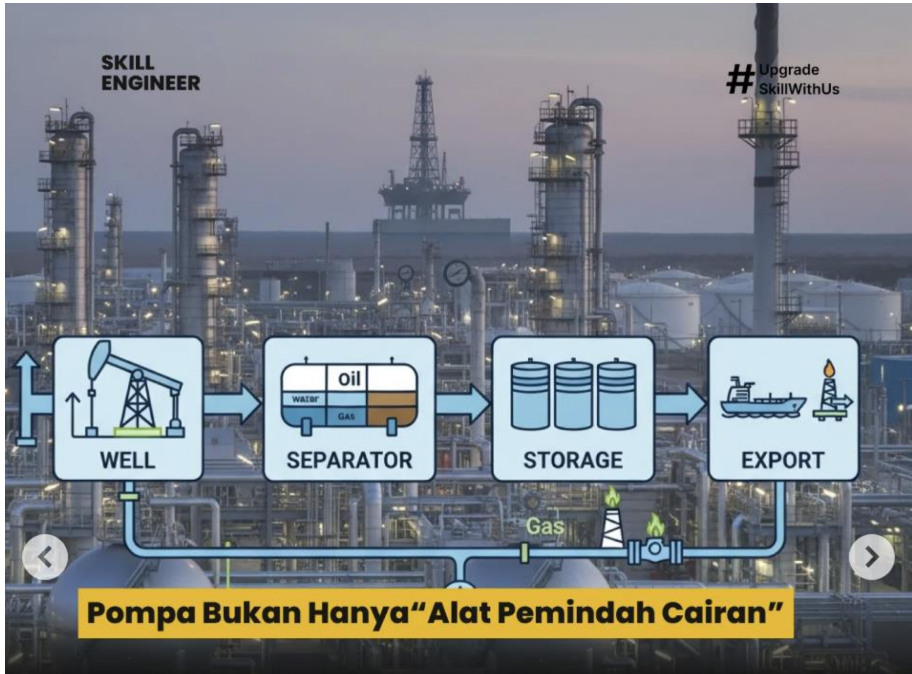

Kamu Tau Gak?
80% Sistem di Oil & Gas
Pasti Punya Komponen
Pompa!

Kamu mungkin sering lihat pompa di plant atau kilang migas, tapi tau gak kalau hampir semua sistem di sana, tergantung sama si “pompa” ini?

Kenapa Hampir Semua Sistem Butuh Pompa?

Karena di dunia migas, hampir semua proses itu tentang memindahkan fluida!

Mulai dari minyak mentah, gas, air injeksi, sampai chemical treatment semuanya butuh pompa buat ngalir dengan tekanan dan flow yang tepat.



Di lapangan, pompa dipakai buat:

- **Transfer oil dari sumur ke separator**
- **Injection air atau kimia ke reservoir**
- **Circulation fluida pendingin dan proses**

Tanpa sistem pompa, produksi bisa berhenti total 😱

Fluid Transport Equipment

A centrifugal pump with a capacity of 100 gpm (22.7 m3/h) at a total discharge head of 150 ft (45.7 m) and requiring 10 ft (3.05 m) NPSH is available to operate an eductor to pump water at 50 ft (15.2 m) below grade. Find the quantity of water that can be delivered at 60 lb/in2 (4.1 bar) gage (see Figure 17).

Solution

The available operating head is 138.6 ft + 50 ft – frictional loss. As a first assumption, the frictional loss is ignored and the head ratio (R_H) is 188.6/40.83 = 4.62 (57.4/12.38 = 4.62).

From Figure 2 at NPSH 33.6 ft (10.24 m), ϵ = 0.9

$$R_H = \frac{H_1 - H_s}{H_2 - H_s}$$

where $H_1 - H_s$ = operating head, ft (m)

$H_2 - H_s$ = discharge head, ft (m)

$$R_w = \epsilon\sqrt{R_H} - 1$$

$$R_w = R_q = 0.9\sqrt{4.62} - 1 = 0.934$$

With QR fixed at 100 gpm (22.7 m3/h),

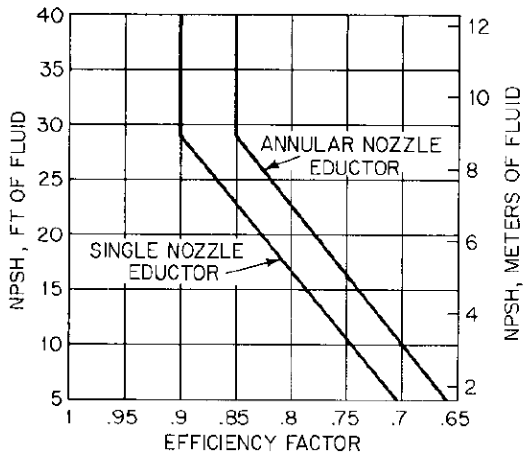


FIGURE 2 NPSH versus efficiency factor (Schutte and Koerting)

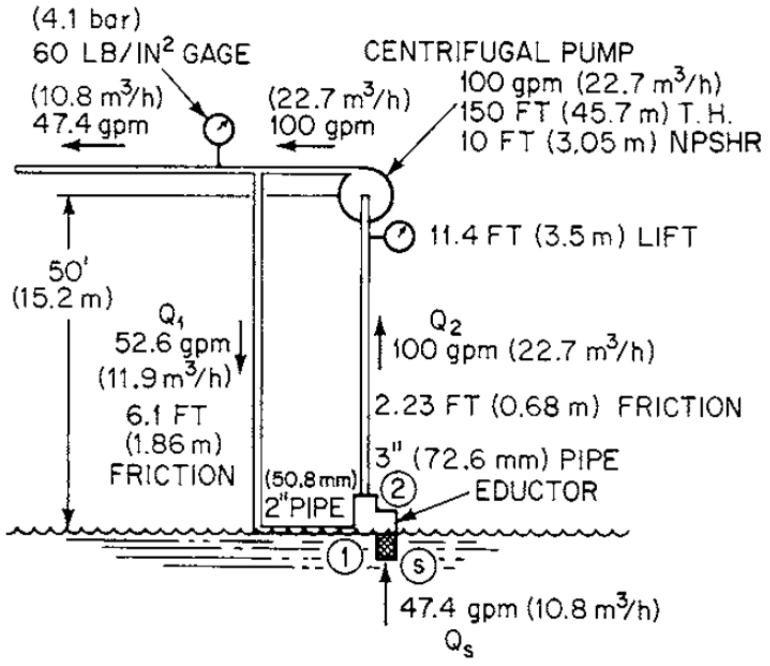


FIGURE 17 Centrifugal-jet pump for Example 4

Laboratory Testing of Crude Oils

Eductor: A liquid jet pump using a liquid as motive fluid

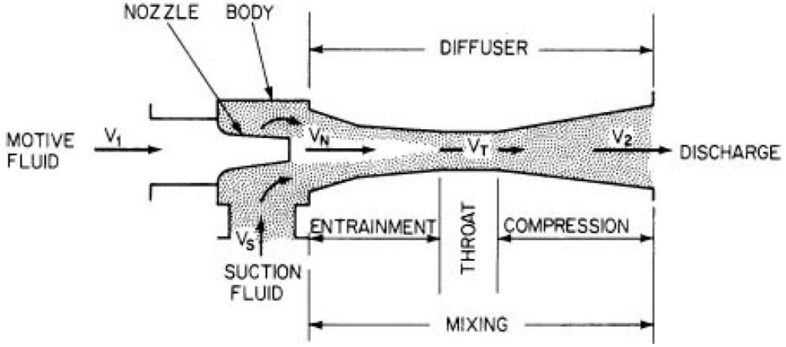


FIGURE 1 Eductor elements and terminology

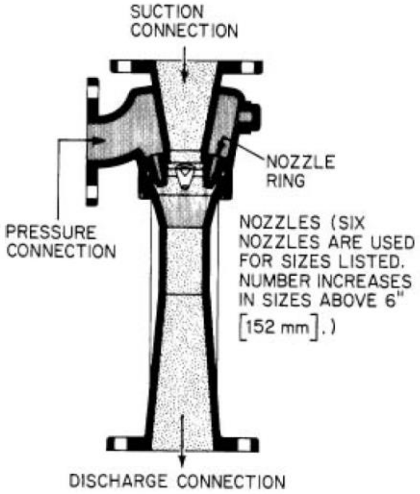


FIGURE 15 Multinozzle eductor (Schutte and Koerting)

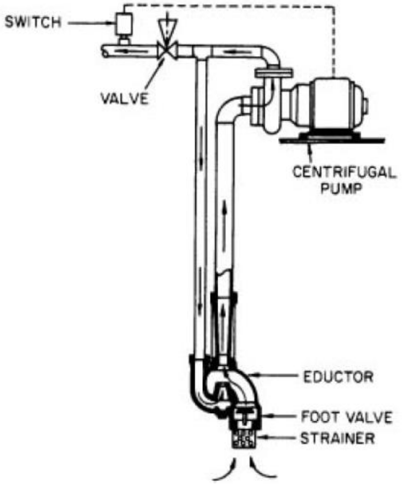


FIGURE 16 Centrifugal-jet pump combination

TABLE 7 Relative capacities (flow rates) of annual eductors

Capacity of standard $1\frac{1}{2}$-in (38.1-mm) mixing eductor, 5 lb/in² (0.34 bar) gage discharge pressure						
Motive pressure, lb/in²(bar) gage	30 (2.1)	40 (2.8)	60 (4.1)	80 (5.5)	100 (6.9)	
Entrainment, ft³/h (m³/h)	2.6 (0.07)	7.1 (0.20)	17.9 (0.51)	22.0 (0.62)	23.8 (0.67)	
Motive flow, gpm (m³/h)	12.7 (2.88)	14.6 (3.31)	17.9 (4.06)	20.7 (4.70)	23.1 (5.24)	
Relative capacities of standard sizes						
Size, in (mm)	$1\frac{1}{4}$ (31.8)	$1\frac{1}{2}$ (38.1)	2 (50.8)	$2\frac{1}{2}$ (63.5)	3 (76.2)	4 (102)
Capacity ratio	0.62	1.00	1.43	2.86	4.76	8.80

Source: Schutte and Koerting.

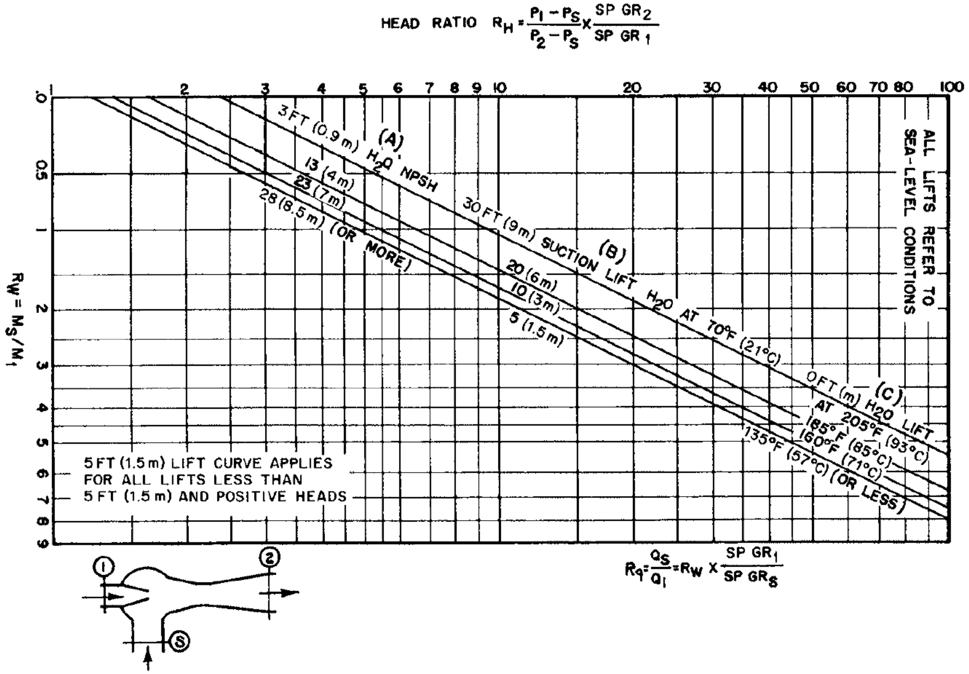


FIGURE 3 Estimating operating ratios for liquid jet eductors. An eductor can be designed for only one head point (Schutte and Koerting)

Fluid Transport Equipment

in USCS units $$Q_1 = \frac{100}{1 + R_q} = \frac{100}{1.934} = 51.7 \text{ gpm}$$

in SI units $$Q_1 = \frac{22.7}{1.934} = 11.7 \text{ m}^3/\text{h}$$

The motive line size is now chosen by selecting a reasonable velocity and frictional loss. Choosing a 2-in (51-mm) pipe size, velocity is 5.57 ft/s (1.70 m/s) and frictional loss is 6.1 ftH_2O (1.86 mH_2O). The revised operating head becomes 188.6 − 6.1 = 182.5 ft (57.4 − 1.86 = 55.6 m) and

in USCS units $$R_q = 0.9\sqrt{182.5/40.83} - 1 = 0.9$$

in SI units $$R_q = 0.9\sqrt{55.6/12.38} - 1 = 0.9$$

then $Q_1 = 100/1.9 = 52.6$ gpm ($22.7/1.9 = 11.9$ m³/h). (This value is close enough so that a third trial is not necessary.) The suction flow that can be delivered is then

in USCS units $$100 - 52.6 = 47.4 \text{ gpm}$$

in SI units $$22.7 - 11.9 = 10.8 \text{ m}^3/\text{h}$$

Fluid Transport Equipment

A pipeline connecting two tanks contains four standard elbows, a plug valve that is fully open and a gate valve that is half open. The line is commercial steel pipe, 25 mm internal diameter, length 120 m. The properties of the fluid are viscosity 0.99 mNM⁻².s, density 998 kg/m3. Calculate the total pressure drop due to friction when the flow rate is 3500 kg/h.

Solution

$$\text{Cross-sectional area of pipe} = \frac{\pi}{4}(25 \times 10^{-3})^2 = 0.491 \times 10^{-3}\,\text{m}^2$$

$$\text{Fluid velocity, } u = \frac{3500}{3600} \times \frac{1}{0.491 \times 10^{-3}} \times \frac{1}{998} = 1.98\ \text{m/s}$$

$$\text{Reynolds number, } Re = (998 \times 1.98 \times 25 \times 10^{-3})/0.99 \times 10^{-3}$$

$$= 49{,}900 = 5 \times 10^4 \qquad (5.4)$$

Absolute roughness commercial steel pipe, Table 5.2 = 0.046 mm

Relative roughness $= 0.046/(25 \times 10^{-3}) = 0.0018$, round to 0.002

From friction factor chart, Figure 5.7, $f = 0.0032$

Miscellaneous losses

fitting/valve	number of velocity heads, K	equivalent pipe diameters
entry	0.5	25
elbows	(0.8×4)	(40×4)
globe valve, open	6.0	300
gate valve, 1/2 open	4.0	200
exit	1.0	50
Total	14.7	735

Method 1, velocity heads

$$\text{A velocity head} = u^2/2g = 1.98^2/(2 \times 9.8) = 0.20\ \text{m of liquid.}$$

$$\text{Head loss} = 0.20 \times 14.7 = 2.94\ \text{m}$$

$$\text{as pressure} = 2.94 \times 998 \times 9.8 = 28{,}754\ \text{N/m}^2$$

$$\text{Friction loss in pipe, } \Delta P_f = 8 \times 0.0032 \frac{(120)}{(25 \times 10^{-3})} 998 \times \frac{1.98^2}{2}$$

$$= 240{,}388\ \text{N/m}^2 \qquad (5.3)$$

$$\text{Total pressure} = 28{,}754 + 240{,}388 = 269{,}142\ \text{N/m}^2 = \underline{\underline{270\ \text{kN/m}^2}}$$

Method 2, equivalent pipe diameters

Extra length of pipe to allow for miscellaneous losses

$$= 735 \times 25 \times 10^{-3} = 18.4\ \text{m}$$

So, total length for ΔP calculation = 120 + 18.4 = 138.4 m

$$\Delta P_f = 8 \times 0.0032 \frac{(138.4)}{(25 \times 10^{-3})} 998 \times \frac{1.98^2}{2} = 277{,}247\ \text{N/m}^2$$

$$= \underline{\underline{277\ \text{kN/m}^2}}$$

Fluid Transport Equipment

A tanker carrying toluene is unloaded, using the ship's pumps, to an on-shore storage tank. The pipeline is 225 mm internal diameter and 900 m long. Miscellaneous losses due to fittings, valves, etc., amount to 600 equivalent pipe diameters. The maximum liquid level in the storage tank is 30 m above the lowest level in the ship's tanks. The ship's tanks are nitrogen blanketed and maintained at a pressure of 1.05 bar. The storage tank has a floating roof, which exerts a pressure of 1.1 bar on the liquid. The ship must unload 1000 tonne within 5 hours to avoid demurrage charges. Estimate the power required by the pump. Take the pump efficiency as 70 per cent. Physical properties of toluene: density 874 kg/m3, viscosity 0.62 mNm^{-2} s.

Solution

$$\text{Cross-sectional area of pipe} = \frac{\pi}{4}(225 \times 10^{-3})^2 = 0.0398 \text{ m}^2$$

$$\text{Minimum fluid velocity} = \frac{1000 \times 10^3}{5 \times 3600} \times \frac{1}{0.0398} \times \frac{1}{874} = 1.6 \text{ m/s}$$

$$\text{Reynolds number} = (874 \times 1.6 \times 225 \times 10^{-3})/0.62 \times 10^{-3}$$

$$= 507{,}484 = 5.1 \times 10^5 \quad (5.4)$$

Absolute roughness commercial steel pipe, Table 5.2 = 0.046 mm
Relative roughness = 0.046/225 = 0.0002
Friction factor from Figure 5.7, $f = 0.0019$
Total length of pipeline, including miscellaneous losses,

$$= 900 + 600 \times 225 \times 10^{-3} = 1035 \text{ m}$$

$$\text{Friction loss in pipeline, } \Delta P_f = 8 \times 0.0019 \times \left(\frac{1035}{225 \times 10^{-3}}\right) \times 874 \times \frac{1.62^2}{2}$$

$$= \underline{\underline{78{,}221}} \text{ N/m}^2 \quad (5.3)$$

Maximum difference in elevation, $(z_1 - z_2) = (0 - 30) = \underline{\underline{-30 \text{ m}}}$

Pressure difference, $(P_1 - P_2) = (1.05 - 1.1)10^5 = \underline{\underline{-5 \times 10^3}} \text{ N/m}^2$

Energy balance

$$9.8(-30) + (-5 \times 103)/874 - (78{,}221)/874 - W = 0 \quad (5.5)$$

$$W = \underline{\underline{-389.2}} \text{ J/kg},$$

$$\text{Power} = (389.2 \times 55.56)/0.7 = 30{,}981 \text{ W}, \quad \text{say } \underline{\underline{31 \text{ kW}}}. \quad (5.6a)$$

Fluid Transport Equipment

Estimate the optimum pipe diameter for a water flow rate of 10 kg/s, at 20°C. Carbon steel pipe will be used. Density of water 1000 kg/m3.

Solution

$$d\text{, optimum} = 293 \times (10)^{0.53}\ 1000^{-0.37} \quad (5.14)$$
$$= \underline{\underline{77.1\ \text{mm}}}$$

use 80-mm pipe.

Viscosity of water at 20°C $= 1.1 \times 10^{-3}$ Ns/m^2,

$$Re = \frac{4G}{\pi \mu d} = \frac{4 \times 10}{\pi \times 1.1 \times 10^{-3} \times 80 \times 10^{-3}} = 1.45 \times 10^5$$

$>$4000, so flow is turbulent.
Comparison of methods:

	Economic diameter
Equation 5.14	180 mm
Peters and Timmerhaus (1991)	4 in. (100 mm)
Nolte (1978)	80 mm

Estimate the optimum pipe diameter for a flow of HCl of 7000 kg/h at 5 bar, 15°C, stainless steel pipe. Molar volume 22.4 m3/kmol, at 1 bar, 0°C.

Solution

Molecular weight HCl = 36.5.

$$\text{Density at operating conditions} = \frac{36.5}{22.4} \times \frac{5}{1} \times \frac{273}{288} = \underline{\underline{7.72\ \text{kg/m}^3}}$$

$$\text{Optimum diameter} = 260\left(\frac{7000}{3600}\right)^{0.52} 7.72^{-0.37} \quad (5.15)$$
$$= \underline{\underline{172.4\ \text{mm}}}$$

use 180-mm pipe.
Viscosity of HCl 0.013 m Ns/m^2

$$Re = \frac{4}{\pi} \times \frac{7000}{3600} \times \frac{1}{0.013 \times 10^{-3} \times 180 \times 10^{-3}} = \underline{\underline{1.06 \times 10^6}}\text{, turbulent}$$

Comparison of methods:

	Economic diameter
Equation 5.15	180 mm
Peters and Timmerhaus (1991)	9 in. (220 mm) carbon steel
Nolte (1978)	7 in. (180 mm) carbon steel

Fluid Transport Equipment

Calculate the line size and specify the pump required for the line shown in Figure 5.15; material ortho-dichlorobenzene (ODCB), flow-rate 10,000 kg/h, temperature 20°C, pipe material carbon steel.

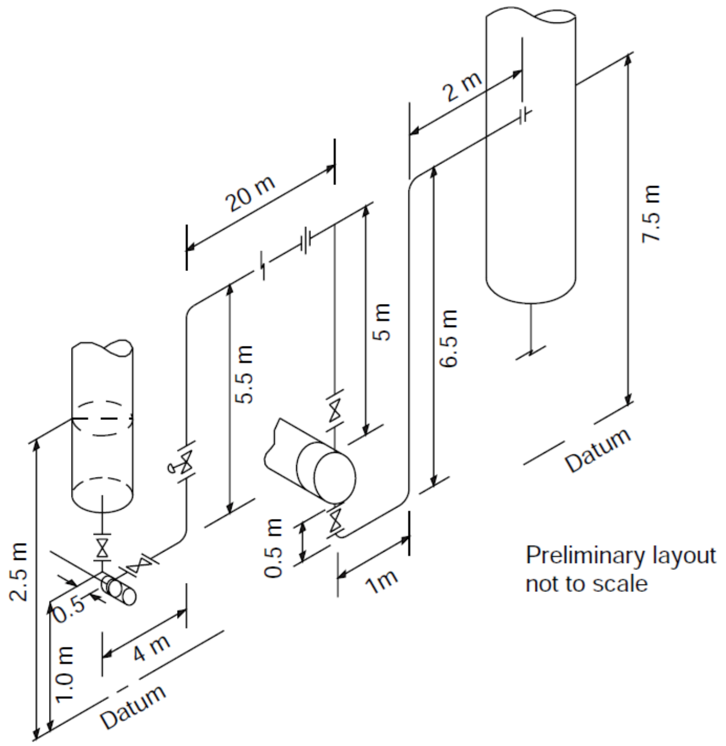


Figure 5.15. Piping isometric drawing (Example 5.8)

Solution

ODCB density at 20°C = 1306 kg/m^3.
Viscosity: 0.9 mNs/m^2 (0.9 cp).

Estimation of pipe diameter required

typical velocity for liquid 2 m/s

$$\text{mass flow} = \frac{10{,}000}{3600} = 2.78 \text{ kg/s}$$

$$\text{volumetric flow} = \frac{2.78}{1306} = 2.13 \times 10^{-3} \text{ m}^3/\text{s}$$

$$\text{area of pipe} = \frac{\text{volumetric flow}}{\text{velocity}} = \frac{2.13 \times 10^{-3}}{2} = 1.06 \times 10^{-3} \text{ m}^2$$

$$\text{diameter of pipe} = \sqrt{\left(1.06 \times 10^{-3} \times \frac{4}{\pi}\right)} = 0.037 \text{ m}$$
$$= 37 \text{ mm}$$

Or, use economic pipe diameter formula:

$$d, \text{ optimum} = 293 \times 2.78^{0.53} \times 1306^{-0.37} \quad (5.14)$$
$$= 35.4 \text{ mm}$$

Take diameter as $\underline{\underline{40 \text{ mm}}}$

$$\text{cross-sectional area} = \frac{\pi}{4}(40 \times 10^{-3}) = 1.26 \times 10^{-3} \text{ m}^2$$

Pressure drop calculation

$$\text{fluid velocity} = \frac{2.13 \times 10^{-3}}{1.26 \times 10^{-3}} = 1.70 \text{ m/s}$$

Friction loss per unit length, Δf_1:

$$Re = \frac{1306 \times 1.70 \times 40 \times 10^{-3}}{0.9 \times 10^{-3}} = 9.9 \times 10^4 \quad (5.5)$$

Absolute roughness commercial steel pipe, table 5.2 = 0.46 mm
Relative roughness, e/d = 0.046/40 = 0.001
Friction factor from Figure 5.7, $f = 0.0027$

$$\Delta f_1 = 8 \times 0.0027 \times \frac{(1)}{(40 \times 10^{-3})} \times 1306 \times \frac{1.7^2}{2} = 1019 \text{ N/m}^2 \quad (5.3)$$
$$= 1.02 \text{ kPa}$$

Design for a maximum flow-rate of 20 per cent above the average flow.

$$\text{Friction loss} = 1.02 \times 1.2^2 = 1.5 \text{ kPa/m}$$

Miscellaneous losses

Take as equivalent pipe diameters. All bends will be taken as 90° standard radius elbow.
Line to pump suction:

$$\begin{aligned} &\text{length} &&= 1.5 \text{ m} \\ &\text{bend, } 1 \times 30 \times 40 \times 10^{-3} &&= 1.2 \text{ m} \\ &\text{valve, } 1 \times 18 \times 40 \times 10^{-3} &&= 0.7 \text{ m} \\ & && \overline{3.4 \text{ m}} \end{aligned}$$

$$\text{entry loss} = \frac{\rho u^2}{2} \text{(see Section 5.4.2)}$$

$$\text{at maximum design velocity} = \frac{1306(1.7 \times 1.2)^2}{2 \times 10^3} = 2.7 \text{ kPa}$$

Control valve pressure drop, allow normal	140 kPa
($\times 1.2^2$) maximum	200 kPa
Heat exchanger, allow normal	70 kPa
($\times 1.2^2$) maximum	100 kPa
Orifice, allow normal	15 kPa
($\times 1.2^2$) maximum	22 kPa

Line from pump discharge:

$$\begin{aligned} &\text{length} = 4 + 5.5 + 20 + 5 + 0.5 + 1 + 6.5 + 2 &&= 44.5 \text{ m} \\ &\text{bends, } 6 \times 30 \times 40 \times 10^{-3} = 7.2 \text{ m} &&= 7.2 \text{ m} \\ &\text{valves, } 3 \times 18 \times 40 \times 10^{-3} = 2.2 \text{ m} &&= 2.2 \text{ m} \\ & && \overline{54.0 \text{ m}} \end{aligned}$$

The line pressure-drop calculation is set out on the calculation sheet shown in Table 5.4.

Pump selection:

flow-rate = $2.13 \times 10^{-3} \times 3600 = 7.7$ m^3/h

differential head, maximum, $\underline{\underline{44 \text{ m}}}$

select single-stage centrifugal (Figure 5.6)

Fluid Transport Equipment

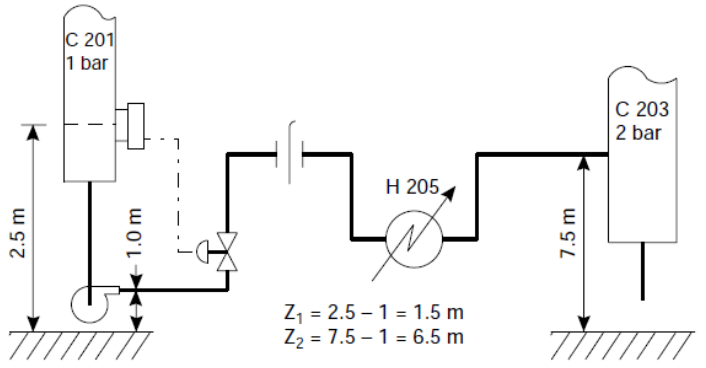
Calculate the line size and specify the pump required for the line shown in Figure 5.15; material ortho-dichlorobenzene (ODCB), flow-rate 10,000 kg/h, temperature 20°C, pipe material carbon steel.

Table 5.5. Pump Specification Sheet (Example 5.8)

	Pump Specification
Type:	Centrifugal
No. stages:	1
Single/Double suction:	Single
Vertical/Horizontal mounting:	Horizontal
Impeller type:	Closed
Casing design press.:	600 kPa
design temp.:	20°C
Driver:	Electric, 440 V, 50 c/s 3-phase.
Seal type:	Mechanical, external flush
Max. flow:	7.7 m^3/h
Diff. press.:	600 kPa (47 m, water)

Table 5.4. Line calculation form (Example 5.4)

Pump and line calculation sheet									
Job no.	Sheet no.	By	RKS, 7/7/79		Checked				
4415A	1								
Fluid		ODCB			DISCHARGE CALCULATION				
Temperature °C		20			Line size mm		40		
Density kg/m^3		1306				Flow	Norm.	Max.	Units
Viscosity mNs/m^2		0.9			u_2	Velocity	1.7	2.0	m/s
Normal flow kg/s		2.78			Δf_2	Friction loss	1.0	1.5	kPa/m
Design max. flow kg/s		3.34			L_2	Line length	54	—	m
					$\Delta f_2 L_2$	Line loss	54		kPa
SUCTION CALCULATION						Orifice	15	22	kPa
Line size mm		40			30%	Control valve	140	200	kPa
	Flow	Norm.	Max.	Units		*Equipment*			
u_1	Velocity	1.7	2.0	m/s		(a) Heat ex.	70	100	kPa
Δf_1	Friction loss	1.0	1.5	kPa/m		(b)	—	—	kPa
L_1	Line length	3.4	—	m		(c)	—	—	kPa
$\Delta f_1 L_1$	Line loss	3.4	5.1	kPa		(6) Dynamic loss	279	403	kPa
$\rho u_1^2/2$	Entrance	1.9	2.7	kPa					
(40 kPa)	Strainer	—	—	kPa	z_2	Static head	6.5	—	m
	(1) Sub-total	5.3	7.8	kPa	$\rho g z_2$		85	85	kPa
						Equip. press (max)	200	200	kPa
z_1	Static head	1.5	1.5	m		Contingency	None	None	kPa
$\rho g z_1$		19.6	19.6	kPa		(7) Sub-total	285	285	kPa
	Equip. press	100	100	kPa	(7) + (6)	Discharge press.	564	685	kPa
	(2) Sub-total	119.6	119.6	kPa	(3)	Suction press.	114.3	111.8	kPa
						(8) Diff. press.	450	576	kPa
(2) − (1)	(3) Suction press	114.3	111.8	kPa	(8)/ρg		34	44	m
	(4) VAP. PRESS.	0.1	0.1	kPa					
(3) − (4)	(5) NPSH	114.2	111.7	kPa	Valve/(6)	Control valve % Dyn. loss	50%		
(5)/ρg		8.7	8.6	m					



Terima Kasih

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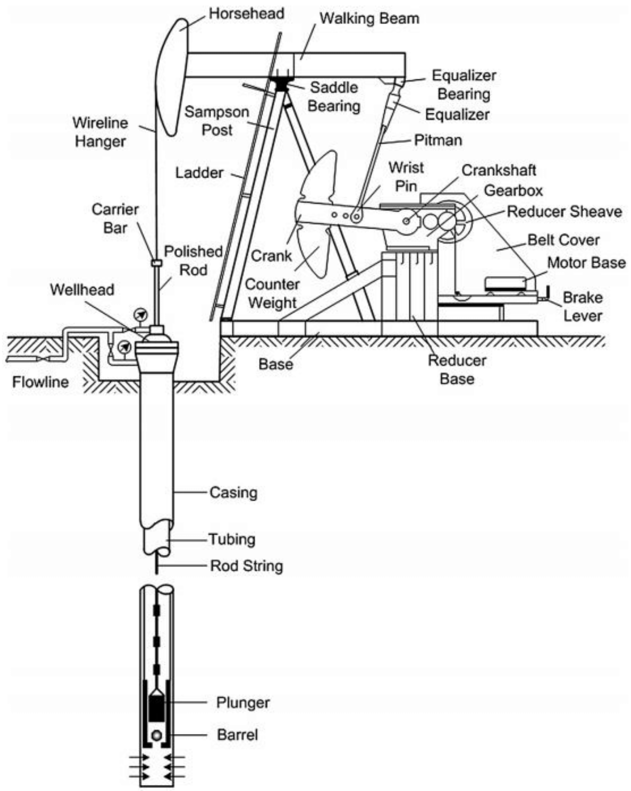
Pompa Angguk (Sucker Rod Pump)



Pompa Angguk (Sucker Rod Pump)

Example 5.6